Impacts of Artificial Dam Construction on Phytoplankton Communities in the Meishan Bay, Zhejiang Province

Dian JIN[1], Qianwen Shao[2], Chenyue Yu[1], Xinfeng Dai[1*]

[1]Key Laboratory of Marine Ecosystem Dynamics, Second Institute of Oceanography, Ministry of Natural Resources, Hangzhou, China
[2]Ningbo Institute of Oceanography, Ningbo, China

Abstract: Meishan Bay became a semi-enclosed artificial bay after the construction of the North Dam and South Dam at the entrances of Meishan Bay between 2012 and 2017. Following the dam construction, Meishan Bay has become a concentrated area primarily for tourism, leisure, and ecological protection, with a significant increase in the frequency of red tides. To investigate the impact of artificial dam construction on the structure of phytoplankton communities in the Meishan Bay, this study conducted surveys of water bodies at nine stations both inside and outside the bay. Results showed that the abundance of phytoplankton within the bay was higher than outside, while the average species diversity index and evenness index were lower within the bay compared to outside, reflecting weaker ecosystem stability within the bay. The construction of dams in the Meishan Bay reduced the water flow velocity, leading to a decrease in the concentration of suspended solids, increased water transparency, and reduced limitations on algal photosynthesis, thus favoring algal reproduction. On the other hand, the convergence of multiple terrestrial rivers within the bay provided a large amount of nutrients for algae, promoting their proliferation but also exacerbating pollution within the bay. The dam construction also altered the content and ratio of nutrients within the bay, resulting in a higher proportion of dinoflagellates. *Skeletonema* sp., *Guinardia delicatula*, and *Prorocentrum minimum* became dominant species in the water. It was clearly showed by this study that Meishan Bay was influenced simultaneously by artificial dam construction and maritime tourism, resulting in a low stability ecosystem. There is a need to enhance pollution management within the bay, guide the development of the tourism industry, and monitor red tides. This research provides a scientific basis for understanding the ecological and environmental impacts of artificial dam construction.

1. Introduction

Intensifying human activities have aggravated marine pollution and eutrophication in coastal waters [1][2][3], and have been associated with an increased frequency of harmful algal blooms in Chinese coastal waters [4]. Changes in coastal ecosystem structure pose potential threats to economic.

development and human health. Artificial dam construction provides benefits such as water storage, flood control, navigation, hydropower generation, and water regulation. However, it can also alter hydrodynamic conditions, reduce sediment delivery to downstream and estuarine areas, and retain large amounts of nutrients. These environmental changes may accelerate or reshape the community structure of aquatic organisms [5]. Marine phytoplankton are widely distributed, highly abundant, and characterized by rapid growth cycles. They are major contributors to global primary production. Because phytoplankton are highly sensitive to environmental changes, they are useful biological indicators for studies of environmental and climatic variability [6].

With the gradual development of the global marine economy, coastal engineering has become an effective approach for supporting coastal development and meeting the strategic demands of marine resource utilization. It also provides substantial social and economic benefits [7]. As a form of development and utilization that alters the natural properties of the marine environment, coastal engineering can disturb marine ecosystems. Such disturbances include reduced water transparency, decreased dissolved oxygen, altered nutrient balance, and declines in biological resources. As important primary producers in marine ecosystems, phytoplankton are highly sensitive to changes in the marine environment. Changes in their community structure may alter the structure of marine food webs and thereby affect the balance of marine ecosystems [8].

At present, studies on the long-term effects of coastal engineering construction on phytoplankton communities remain limited [8][9][10]. Among these studies, research on the ecological impacts of nearshore artificial dam construction is particularly scarce. The ecological effects of nearshore artificial dam construction include regulation of river discharge, reduction of sediment flux, changes in water temperature, erosion of estuarine deltas, alterations

1102892332@qq.com, 2479sqw@163.com, 3037013545@qq.com, *xinfengdai@sio.org.cn

in the composition and distribution of nutrients, changes in the structure and distribution of phytoplankton, and habitat fragmentation in adjacent marine areas [5].

Meishan Bay is an important component of Ningbo–Zhoushan Port. It was originally a north–south open waterway. Between 2012 and 2017, the North Dam and South Dam were constructed on its landward side, and their closure transformed the bay into a semi-enclosed artificial lagoon [11]. The dams altered the hydrodynamic conditions within the bay, resulting in relatively calm waters and reduced suspended sediment concentrations [12]. With industrial upgrading, the land areas on both sides of Meishan Bay have shifted from fisheries and agriculture toward industrial development, forming an industrial cluster dominated by petrochemicals, steel, energy, papermaking, and shipbuilding. In contrast, the bay itself has become a functional area mainly focused on tourism, recreation, and ecological conservation. After dam construction, red tides occurred repeatedly in Meishan Bay, reaching a peak in 2018 [13].

To investigate the effects of artificial dam construction on the ecosystem of Meishan Bay, nine sampling stations were established inside and outside the bay. Surface and bottom seawater samples were collected at each station. By analyzing phytoplankton distribution in the surface and bottom waters, this study aimed to characterize the spatial distribution patterns of phytoplankton and further reveal the ecological effects of artificial dam construction on the nearshore bay ecosystem.

2. Material and methods

2.1 Sampling sites

Nine sampling stations were established inside and outside Meishan Bay (Table 1). Phytoplankton water samples were collected in winter 2022 and spring 2023(Figure. 1). Water samples from different depths were used to analyze the phytoplankton community structure in specific water layers. Seawater samples were collected using a 30 L Niskin bottle, and 500 mL of seawater was transferred into a 550 mL PET bottle for phytoplankton analysis. The phytoplankton samples were fixed with Lugol's solution at a final concentration of 1% and stored in the dark until they were transported back to the laboratory.

Physicochemical parameters of the water column were measured in situ using a CTD multiparameter probe (Sea-Bird, SBE 19plus, USA). Dissolved inorganic nitrogen (DIN) was calculated as the sum of nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+) concentrations. Nitrate, nitrite, and phosphate were analyzed using a continuous-flow nutrient analyzer (Skalar, Netherlands). One-way analysis of variance (ANOVA) in Excel 2019 was used to test differences in phytoplankton samples and environmental factors between surface and bottom waters, as well as between stations inside and outside the bay.

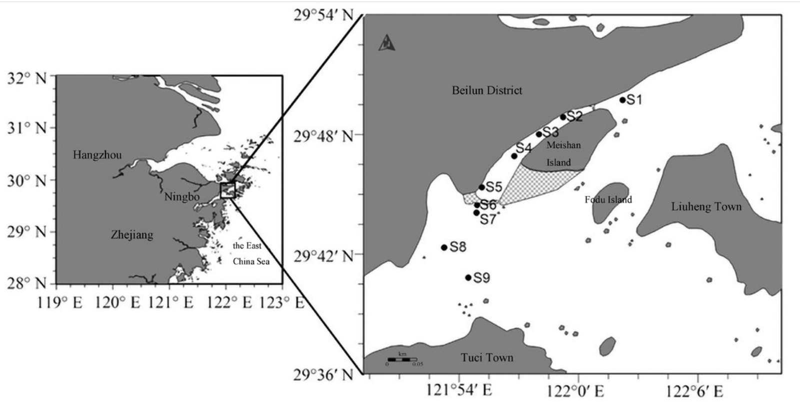

Fig. 1. The sampling stations in Meishan Bay

Table 1. Information of the sampling stations in Meishan Bay

Sampling station	Longitude/E	Latitude /N	Depth /m	Location	Sampling time
S1	122.03704	29.82861	2.2	Outside the bay	2022.11
S2	121.98707	29.81434	8.0	Inside the bay	2022.11
S3	121.96684	29.80006	9.5	Inside the bay	2022.11
S4	121.94603	29.78221	6.2	Inside the bay	2022.11
S5	121.91906	29.75604	5.1	Inside the bay	2022.11
S6	121.91527	29.74115	3.0	Outside the bay	2023.05
S7	121.91461	29.73464	4.6	Outside the bay	2022.11
S8	121.88765	29.70570	5.6	Outside the bay	2023.05
S9	121.90792	29.68052	8.3	Outside the bay	2023.05

2.2 Data processing

Before analysis, the preserved phytoplankton samples were gently mixed, and a 1 mL aliquot was transferred to a 1 mL Sedgewick–Rafter counting chamber (PYSER-SGI, UK). The chamber was covered with a coverslip and examined using an inverted light microscope (Olympus CKX53, Japan) for taxonomic identification and cell enumeration. Phytoplankton abundance was expressed as cells per liter (cells/L). Community diversity and evenness were evaluated using the Shannon-Wiener diversity index (H′) and Pielou's evenness index (J′), respectively. Dominant species were identified based on the dominance index, and species with Y > 0.02 were considered dominant.

3. Results

3.1 Spatial distribution of phytoplankton in surface water of Meishan Bay

In the surface waters of Meishan Bay, a total of 30 phytoplankton species were identified, including 18 diatom species, 8 dinoflagellate species, 1 cyanobacterial species, 1 cryptophyte species, and 2 euglenophyte species. No single species was detected at all sampling stations. Among the nine stations, phytoplankton abundance was highest at S2 and lowest at S7. Stations S2, S3, S4, and S5 were located inside the bay, where phytoplankton abundance ranged from 201,000 to 1,200,000 cells/L. Stations S6, S8, and S9 were located on the southern outer side of the bay, where abundance ranged from 101,000 to 200,000 cells/L. Stations S1 and S7 were located on the northern and southern outer sides of the bay, respectively, where abundance ranged from 17,000 to 50,000 cells/L. The Shannon–Wiener diversity index was highest at S4 and lowest at S5. The index ranged from 1.11 to 1.90 at S4, S6, and S7; from 0.81 to 1.10 at S1 and S3; and from 0.30 to 0.80 at S2, S5, S8, and S9. Pielou's evenness index was highest at S7 and lowest at S5. The index ranged from 0.21 to 0.25 at S1 and S7; from 0.11 to 0.20 at S2, S4, S6, S8, and S9; and from 0.05 to 0.10 at S3 and S5(Figure. 2 and Figure. 3).

The dominant species in the surface waters were *Skeletonema* sp., *Guinardia delicatula*, and *Prorocentrum minimum*. Diatoms occurred at all stations and contributed the highest proportion of phytoplankton abundance at all stations except S5. Dinoflagellates were mainly distributed at the inner-bay stations and showed the highest relative abundance at S5 near Wanren Beach, where they far exceeded diatoms. Cyanophyta, Cryptophyta, and Euglenophyta generally had low abundances, although Cyanophyta reached their highest abundance at S1 and exceeded diatoms there, while Cryptophyta reached their highest abundance at S6.

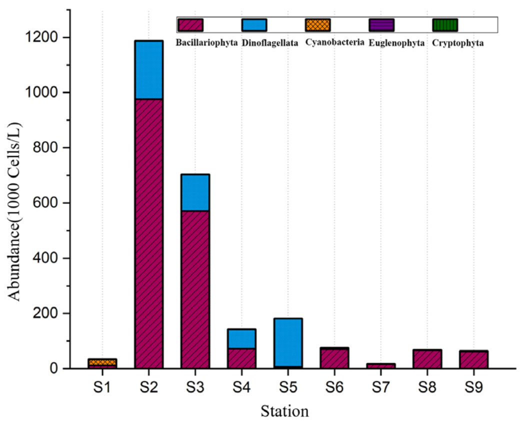

Fig. 2. Abundance of phytoplankton phylum in surface water in different stations of Meishan Bay

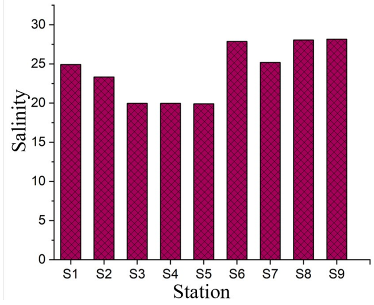

Fig. 3. Salinity (B) in surface water at each station site in Meishan Bay

3.2 Spatial distribution of phytoplankton in bottom water of Meishan Bay

In the bottom waters of Meishan Bay, a total of 27 phytoplankton species were identified, including 24 diatom species and 3 dinoflagellate species, whereas Cyanophyta, Cryptophyta, and Euglenophyta were not detected. No single species occurred at all sampling stations. Among the six stations, phytoplankton abundance was highest at S2 and lowest at S7. Abundance ranged from 150,000 to 300,000 cells/L at S2, S3, and S4, from 21,000 to 150,000 cells/L at S1 and S5, and was 18,000 cells/L at S7. The Shannon–Wiener diversity index was highest at S5 and lowest at S1, with values ranging from 0.40 to 1.50, while Pielou's evenness index was highest at S7 and lowest at S4, ranging from 0.10 to 0.20(Figure. 4).

The dominant species in the bottom waters were *Skeletonema* sp., *Guinardia delicatula*, and *Prorocentrum minimum*. Diatoms occurred at all stations and showed higher abundances than other phytoplankton groups, with the highest abundance observed at S2. Dinoflagellates were detected only at the inner-bay stations, including S2, S3, S4, and S5, and made their highest contribution to total phytoplankton abundance at S2. Cyanophyta, Cryptophyta, and Euglenophyta were not detected in the bottom waters.

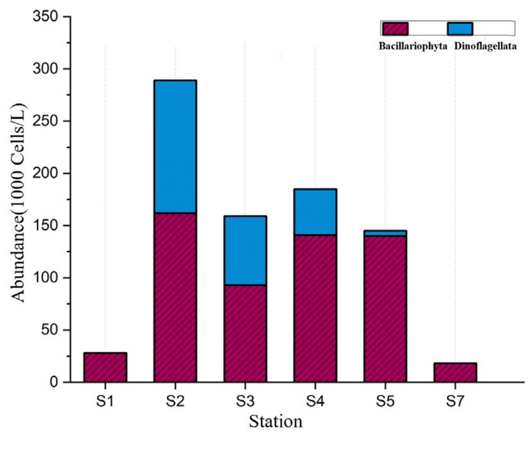

Fig. 4. Abundance of phytoplankton phylum in surface water in different stations of Meishan Bay

3.3 Phytoplankton Distribution Patterns in Meishan Bay

Mean phytoplankton abundance was generally higher in the surface waters than in the bottom waters. The mean phytoplankton diversity index was also generally higher in the surface waters, whereas the mean evenness index was generally lower in the surface waters than in the bottom waters. In both the surface and bottom waters of Meishan Bay, mean phytoplankton abundance was higher inside the bay than outside the bay. The mean diversity index was higher in the surface waters than in the bottom waters, and was slightly lower in the surface waters inside the bay than outside the bay. The mean evenness index was lower in the surface waters than in the bottom waters, and was lower inside the bay than outside the bay (Figure. 5).

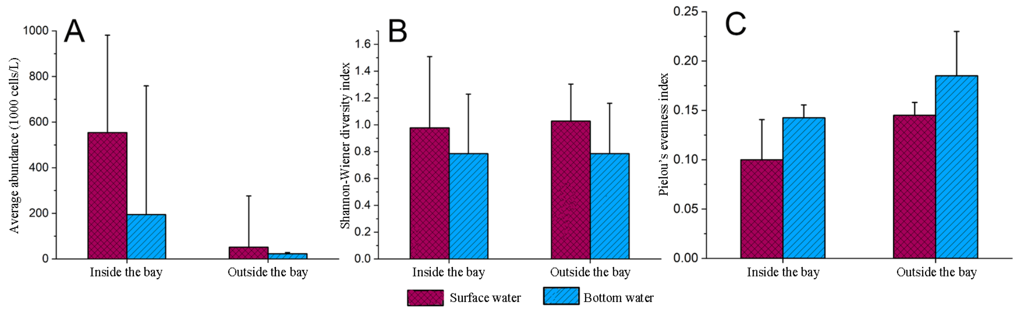

Fig. 5. Average abundance (A), Shannon-Wiener diversity index (H′) (B) and Pielou's evenness index (J′) (C) of phytoplankton in surface and bottom water of Meishan Bay

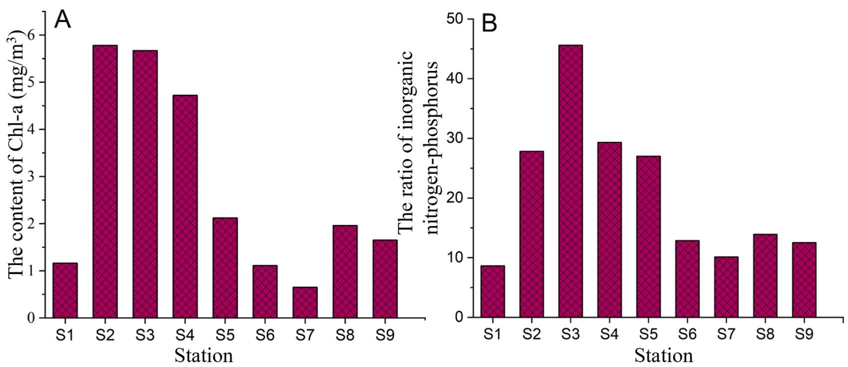

Fig. 6. The content of Chl-a(A)and the ratio of inorganic nitrogen-phosphorus (B) in surface water at each station site in Meishan Bay

3.4 Various parameters in surface water and bottom water in Meishan Bay

Water depth at the stations in Meishan Bay ranged from 2.2–9.5 m, with a mean depth of 5.8 m. Station S1 was the shallowest, whereas S3 was the deepest. Water transparency ranged from 0.1–4.9 m, with a mean value of 1.48 m. The highest transparency was observed at S5 and the lowest at S1. Transparency at the inner-bay stations (S2, S3, S4, and S5) was higher than that at the outer-bay stations (S1, S6, S7, S8, and S9).

In the surface waters of Meishan Bay, dissolved inorganic nitrogen (DIN) concentrations ranged from 0.167–0.417 mg/L, with a mean value of 0.305 mg/L. The lowest DIN concentration was observed at S2 and the highest at S8. Dissolved inorganic phosphorus (DIP) concentrations ranged from 0.005–0.038 mg/L, with a mean value of 0.022 mg/L. The lowest DIP concentration was observed at S3 and the highest at S7. DIN and DIP concentrations in the surface waters of the inner-bay stations (S2, S3, S4, and S5) were lower than those at the outer-bay stations (S1, S6, S7, S8, and S9).

The DIN:DIP ratio in the surface waters of Meishan Bay ranged from 8.61–45.6, with a mean value of 20.86. The lowest value was observed at S1 and the highest at S3. The DIN:DIP ratio at the inner-bay stations (S2, S3, S4, and S5) was higher than that at the outer-bay stations (S1, S6, S7, S8, and S9). Correlation analysis showed that the DIN:DIP ratio was positively correlated with phytoplankton abundance outside the bay but negatively correlated with phytoplankton abundance inside the bay (Figure. 6).

4. Discussion

Artificial dam construction in Meishan Bay first altered the hydrodynamic environment and subsequently changed the phytoplankton community structure. Meishan Bay is located in the coastal waters of Ningbo, Zhejiang Province. Before dam construction, it was directly connected to the East China Sea and was influenced by the Changjiang Estuary, the Qiantang River, and East China Sea tides, resulting in frequent water exchange and relatively high suspended sediment concentrations [14]. After the construction of the northern and southern dams, suspended sediment concentrations in the bay decreased [15]. In the present study, water transparency was higher inside the bay than outside the bay, which may enhance phytoplankton photosynthesis and promote phytoplankton growth in the inner bay. In contrast, reduced light availability in the bottom waters may inhibit phytoplankton growth. Similar results were reported by Li et al. [16], who suggested that lower phytoplankton abundance in nearshore waters than in offshore waters around the Zhoushan Islands in spring was probably caused by higher suspended sediment concentrations and turbidity.

The closure of the two dams also altered the tidal regime and flow velocity in Meishan Bay, weakening hydrodynamic conditions inside the bay, increasing water-column stability, and reducing particle settling rates [15]. Increased water-column stability can enhance phytoplankton production and even promote algal blooms [17]. In contrast, waters outside Meishan Bay are characterized by more complex currents, higher turbidity, faster flow velocity, and higher particle settling rates, which are unfavorable for phytoplankton growth. Previous research showed that diatoms, dinoflagellates, and cyanobacteria are most sensitive to changes in flow velocity. Diatoms and cyanobacteria account for the largest proportions when flow velocity is below 0.05 m/s; diatoms, dinoflagellates, and green algae increase at 0.05–0.1 m/s; and diatoms become absolutely dominant when flow velocity exceeds 0.1 m/s [18]. In the present study, dinoflagellates were not detected outside the bay, suggesting that their growth may be strongly inhibited under high-flow and low-transparency conditions.

Artificial dam construction in Meishan Bay affected nutrient exchange, altered nutrient stoichiometry, and thereby changed the phytoplankton community structure. Nutrients form the material basis of marine biological resources and are key factors limiting phytoplankton growth; changes in the input of limiting nutrients can alter phytoplankton density. Compared with the waters outside the bay, Meishan Bay receives nutrient inputs from several land-derived rivers [19], providing favorable conditions for phytoplankton growth. Inorganic phosphorus and inorganic nitrogen are important nutrients for phytoplankton. However, their concentrations were lower inside the bay than outside the bay, possibly because nutrient consumption by phytoplankton exceeded terrestrial nutrient inputs, resulting in lower residual nutrient concentrations in the water column. Previous studies have shown that nutrient levels in Meishan Bay are affected not only by external inputs and release from environmental media, but also by phytoplankton uptake in different seasons [20].

The N:P ratio was higher inside the bay than outside the bay. Correlation analysis showed that the N:P ratio was positively correlated with phytoplankton outside the bay but negatively correlated with phytoplankton inside the bay, indicating that the excessively high N:P ratio inside the bay may have limited phytoplankton growth. Several studies have shown that, under phosphorus limitation, phytoplankton communities may shift from diatom dominance toward dinoflagellates or other non-diatom groups [21][22]. Phosphorus limitation can also be influenced by other factors. In the Changjiang Estuary, for example, dissolved inorganic nitrogen, inorganic phosphorus, and silicate concentrations are affected by Changjiang diluted water and generally decrease from nearshore to offshore areas. Suspended particulate matter can partly regulate phosphate distribution, while biological uptake can further intensify phosphorus limitation, indicating that phytoplankton play an important role in shaping nutrient structure in the Changjiang Estuary [23]. In spring and autumn, the outer area of Meishan Bay was moderately polluted and was mainly characterized by moderately phosphorus-limited potential eutrophication and oligotrophic conditions. In contrast, the inner bay was mainly characterized by slight pollution, phosphorus-limited potential eutrophication, and phosphorus-limited eutrophication [19].

Artificial dam construction in Meishan Bay may increase the likelihood of red tide occurrence. After dam construction, red tides occurred repeatedly in Meishan Bay and peaked in 2018 [13]. In the present study, the mean diversity index and mean species evenness index of phytoplankton in the surface waters were both lower inside the bay than outside the bay, indicating weaker ecosystem stability in the surface waters and a higher potential for red tide formation. Lower phytoplankton diversity and species richness may also indicate a higher degree of eutrophication in this area, with greater pollution inside the bay than outside the bay. Previous studies have shown that coastal engineering can affect phytoplankton composition and increase the frequency of harmful red tides [24] [25].

Acknowledgments

Supported by the National Science Foundation of China (42276131), and Scientific Research Fund of the Second Institute of Oceanography, MNR (grand no. SZ2402)

References

1. Y. L. Lu, J. J. Yuan, X. T. Lu, et al., “Major threats of pollution and climate change to global coastal ecosystems and enhanced management for sustainability,” Environmental Pollution, vol. 239, pp. 670–680, Aug. 2018, doi: 10.1016/j.envpol.2018.04.016.
2. Y. J. Wang, D. Y. Liu, W. P. Xiao, et al., “Coastal eutrophication in China: Trend, sources, and ecological effects,” Harmful Algae, vol. 107, Art. no. 102058, Jul. 2021b, doi: 10.1016/j.hal.2021.102058.
3. F. Wang, X. G. Li, X. H. Tang, et al., “The seas around China in a warming climate,” Nature Reviews Earth & Environment, vol. 4, no. 8, pp. 535–551, Aug. 2023, doi: 10.1038/s43017-023-00453-6.
4. J. J. Wang, A. F. Bouwman, X. C. Liu, et al., “Harmful algal blooms in Chinese coastal waters will persist due to perturbed nutrient ratios,” Environmental Science & Technology Letters, vol. 8, no. 3, pp. 276–284, Mar. 2021a, doi: 10.1021/acs.estlett.1c00012.

5. X. Zhang, C. Fang, Y. Wang, X. Lou, Y. Su, and D. Huang, “Review of effects of dam construction on the ecosystems of river estuary and nearby marine areas,” Sustainability, vol. 14, no. 10, Art. no. 5974, May 2022, doi: 10.3390/su14105974.
6. P. G. Falkowski, R. T. Barber, and V. Smetacek, “Biogeochemical controls and feedbacks on ocean primary production,” Science, vol. 281, no. 5374, pp. 200–206, Jul. 1998, doi: 10.1126/science.281.5374.200.
7. S. Vazdani, G. R. Sabzghabaei, S. Dashti, M. Cheraghi, R. Alizadeh, and A. Hemmati, “FMEA techniques used in environmental risk assessment,” Environment & Ecosystem Science, vol. 1, no. 2, pp. 16–18, 2017, doi: 10.26480/ees.02.2017.16.18.
8. Z. W. Li and L. T. Cui, “Phytoplankton community response to coastal engineering construction in the Caofeidian Sea, China,” Journal of Coastal Research, Special Issue no. 82, pp. 218–223, 2018a, doi: 10.2112/SI82-032.1.
9. D. Marić Pfannkuchen, R. Kraus, J. Godrijan, N. Supić, T. Djakovac, and R. Precali, “Phytoplankton response to climatic and anthropogenic influences in the north-eastern Adriatic during the last four decades,” Estuarine, Coastal and Shelf Science, vol. 115, pp. 98–112, Dec. 2012, doi: 10.1016/j.ecss.2012.02.003.
10. Ž. Ninčević-Gladan, M. Bužančić, G. Kušpilić, et al., “The response of phytoplankton community to anthropogenic pressure gradient in the coastal waters of the eastern Adriatic Sea,” Ecological Indicators, vol. 56, pp. 106–115, Sep. 2015, doi: 10.1016/j.ecolind.2015.03.018.
11. L. M. Sun, W. D. Wang, F. Gao, C. L. Cao, and J. F. Tang, “Distribution and influencing factors of plankton in an artificial lagoon in Ningbo,” Asian Journal of Ecotoxicology, vol. 13, no. 4, pp. 60–67, 2018, doi: 10.7524/AJE.1673-5897.20180512001. (in Chinese)
12. Y. Xu, Y. Wang, S. Hu, Y. Zhu, J. Zuo, and J. Zeng, “Study on the impact of the coastline changes on hydrodynamics in Xiangshan Bay,” Applied Sciences, vol. 13, no. 14, Art. no. 8071, 2023, doi: 10.3390/app13148071.
13. Q. W. Shao, Z. Z. Lin, C. X. Zhou, P. Zhu, and X. J. Yan, “Succession of bacterioplankton communities over complete Gymnodinium–diatom bloom cycles,” Science of the Total Environment, vol. 709, Art. no. 135951, Mar. 2020, doi: 10.1016/j.scitotenv.2019.135951.
14. H. Z. Yan, Z. Y. Xu, W. J. Chen, L. Wang, Q. Liu, L. L. Gao, D. D. Hou, D. M. Zhang, and K. Wang, “Spatial distribution of planktonic archaeal community in the coastal waters around Meishan Island in spring,” Acta Microbiologica Sinica, vol. 61, no. 9, pp. 2709–2725, 2021, doi: 10.13343/j.cnki.wsxb.20200670. (in Chinese)
15. L. N. Cai, W. Yu, W. Shao, D. L. Tang, and I. M. Belkin, “Satellite observations of suspended sediment near Ningbo North Dyke, China,” Advances in Space Research, vol. 64, no. 7, pp. 1415–1422, Oct. 2019, doi: 10.1016/j.asr.2019.07.013.
16. Z. H. Li, Y. D. Zhou, Y. Z. Zhang, Z. J. Zhu, and K. D. Xu, “Characteristics of phytoplankton community in Zhoushan Sea Area in spring, 2014,” Journal of Zhejiang Ocean University (Natural Science), vol. 37, no. 5, pp. 405–411, 2018b, doi: 10.3969/j.issn.1008-830X.2018.05.005. (in Chinese)
17. X. F. Dai, D. D. Lu, P. Xia, H. X. Wang, P. X. He, and D. R. Li, “Impact of water stratification on Prorocentrum donghaiense Lu blooms in high-frequency HAB occurrence area of the East China Sea in 2010–2011,” Oceanologia et Limnologia Sinica, vol. 45, no. 2, 2014, doi: 10.11693/hyhz20121105001. (in Chinese)
18. Y. J. Li, H. T. Zhang, J. Xiao, X. L. Qiu, and B. L. Wang, “Effects of river hydrology on phytoplankton dynamics in dammed rivers,” Earth and Environment, vol. 47, no. 6, pp. 857–863, 2019, doi: 10.14050/j.cnki.1672-9250.2019.47.144. (in Chinese)
19. M. Zhang, S. Q. Mao, Q. T. Lou, Q. W. Shao, F. Li, and Z. Z. Lin, “Spatial-temporal variations and eutrophication analysis of nutrients in Meishan Bay in 2018,” Marine Environmental Science, vol. 39, no. 6, pp. 853–859, 2020, doi: 10.12111/j.mes.20190210. (in Chinese)
20. M. Zhang, G. Chen, Z. T. Luo, X. Sun, and J. Xu, “Spatial distribution, source identification, and risk assessment of heavy metals in seawater and sediments from Meishan Bay, Zhejiang coast, China,” Marine Pollution Bulletin, vol. 156, Art. no. 111217, Jul. 2020, doi: 10.1016/j.marpolbul.2020.111217.
21. R. Riegman, M. de Boer, and L. de Senerpont Domis, “Growth of harmful marine algae in multispecies cultures,” Journal of Plankton Research, vol. 18, no. 10, pp. 1851–1866, Oct. 1996, doi: 10.1093/plankt/18.10.1851.
22. J. K. Egge, “Are diatoms poor competitors at low phosphate concentration?” Journal of Marine Systems, vol. 16, pp. 191–198, 1998, doi: 10.1016/S0924-7963(97)00113-9.
23. B. Z. He, Y. Wang, B. Wang, S. Q. Lu, K. Lei, L. Q. Li, and Q. G. Cheng, “Spatiotemporal characteristics of nutrients in the Yangtze River Estuary from 2016 to 2021 and their influencing factors,” Research of Environmental Sciences, vol. 37, no. 2, pp. 221–232, 2024, doi: 10.13198/j.issn.1001-6929.2023.10.04. (in Chinese)
24. G. Friedl and A. Wüest, “Disrupting biogeochemical cycles—Consequences of damming,” Aquatic Sciences, vol. 64, no. 1, pp. 55–65, 2002, doi: 10.1007/s00027-002-8054-0.
25. W. M. Lum, G. Benico, H. Doan-Nhu, et al., “The harmful raphidophyte Chattonella (Raphidophyceae) in Western Pacific: Its red tides and associated fisheries damage over the past 50 years (1969–2019),” Harmful Algae, vol. 107, Art. no. 102070, Jul. 2021, doi: 10.1016/j.hal.2021.102070